THE KNOWLEDGE EXPLOSION
Liberation and Limitation
The Centennial Colloquium
At Boston College
Edited by Francis Sweeney, S.J.
New York: Farrar, Straus & Giroux
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NsG-467

3. New and Strange Systems

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7a. [1966] 8p refs

The impact of the science explosion is most profitably examined in the context of the global aspects of human development, particularly from the evolutionary standpoint. In such an examination we must keep in mind that the rate effected is a culmination of all the history of life on our planet. We must also consider the possibility that a similar autocatalytic rush of development may be unfolding on the planets of millions of other stars in our galaxy and in millions of other galaxies. Man may not be the final product of organic evolution.

See following 3 pages

If the age of the earth is 10^9 to 10^{10} years and recorded history is 10^4 years old, then all that human ingenuity has thus far wrought has been accomplished in but 1/100,000 of the earth's history. Modern science, as we know it, is of the order of 10^2 years old; hence the miracles performed by science were accomplished in the last millionth part of the world's existence. Evolution is now changing the face of the earth and the balance of living things—among other factors, through the rapid spread of *Homo sapiens* over the earth not only by slow somatic adaptations but by changes made possible by man's mind—specifically, by his ability to express his thoughts in written and spoken symbols (see Addendum).

Even if he so desired, man could not stem this onward rush of scientific and technological development because of the elemental drive that underlies the explosive process, which has the autocatalytic properties of a chain reaction. It is better, therefore, to attempt to make the process more effective and to channel it in directions most propitious from the human viewpoint.

How Can Science Be Made More Effective?

Teaching EDUCATION

The necessity of overhauling the teaching of science at all levels has been recognized; effective steps have already been taken at the *high-school level*. The large-scale effort to revise the textbooks and laboratory manuals in physics[1] has proved its worth; teaching aids and new curricula in biology and other sciences are also being strengthened. At the university level, however, the revision has scarcely started. One of the chief obstacles is the rigidity of traditional departmental organization of teaching according to disciplines—physics, chemistry, biology. These are convenient points of reference, especially for undergraduate teaching, but they are not inventions of nature. Since the interstitial areas frequently offer obvious promise, how can the gaps created by the early pioneers of didactic university science be bridged? It would help if more incentive, status, and financial reward than is now accorded were offered to teachers and to others who would like to make contributions in this general area. Why

[1] "Educational Services Incorporated, 1959 Progress Report. A Review of the Secondary School Physics Program of the Physical Science Study Committee, Initiated at the Massachusetts Institute of Technology" (Watertown, Mass.: Educational Services Incorporated, 1960).

not provide fellowships for training and research in the teaching of science as attractive as those now available for scientific research? Perhaps substantial prizes for new discoveries in improving the teaching of science would be stimulating.

Research: The Emerging Importance of Centers

The large center where costly hardware and technical staff can be housed and where staff from various departments can work on a common problem is becoming an important feature of the typical university's research establishment and will doubtless receive growing support as more and more universities learn how to adapt the idiom to their programs. In a few institutions, centers have expanded to a point where they may supersede the disciplinary department in terms of budget, personnel, and space.

The inter-university national laboratories, such as those at Brookhaven, Argonne, and Oak Ridge, provide an autonomous research establishment, supervised by the universities and by federal agencies, which, without disturbing the programs of the sponsoring universities, has proved capable of generating research capability in particular fields far greater than the individual universities could do. New national inter-university laboratories might be established and dedicated not only to atomic energy but also to other subjects such as molecular biology, genetics, developmental biology, and mental health. These might become the American counterparts of the Max Planck Institutes of Germany, the Medical Research Council Units of Great Britain, and the Academies of Science and Medicine of the Soviet Union, which have well served the research needs of their respective countries. Such national laboratories, unrestrained by the disciplinary requirements imposed by the teaching function of the university, yet maintaining a close relationship with the universities, could move rapidly when new fields open.

Need for a New Science Intelligence Capability

The proliferation of scientific research has already precipitated a crisis in library and communications administration. This will not be solved alone by miniaturization or by machine processing, storage, and retrieval. There is a need for the evaluation of published work, not so much to eliminate poor or mediocre material as to identify good material and most rapidly bring it to the attention of professional personnel. Editorial boards of journals could help in producing a starred list of papers and reviews that merited special attention.

We agree heartily with Dr. Goudsmit that we need not only translators of foreign literature but also *interpreters* of the ideas and thoughts of those working in fields remote from our own areas of competency. Scientists talented in this way exist, but their numbers should be greatly increased, their reward should be substantial, and the conditions of tenure and work should be attractive. Interpreters are needed who have reference to the public, the lay scientist, and the professional scientist.

At a higher level of creativity, experiments should be devised to develop a "corporate science" within particular problem areas. By this is meant provision of facilities that favor an optimum in the close personal interaction of scientists assembled from disparate disciplines pertinent to the problem, who not only are competent practicing scientists in both experimental and theoretical fields but possess personalities that lend themselves to interpersonal communication. Last, but perhaps most important, the participating scientists should be highly motivated to advancing the field. Such corporate science is not teamwork in the usual sense of laboratory science—that is, division of labor required because of the extent and complexity of the problem. Rather, it would be an effort in mutual education, stimulation, and full sharing of ideas. Along these lines, a program dedicated to advance of the neurosciences is currently being devised;[2] the prognosis is promising.

The improvement of coordination, evaluation, and interpretation of scientific results deserves the attention of university and governmental agencies. Substantial experiments may be made to determine the best way of accomplishing the desired end. It is not inconceivable that in the aggregate this type of intelligence processing, communication, and interpretation will reach large dimensions in terms of personnel, organization, and cost. It should be possible to create an effective integrative organization in *conjunction* with the present scientific research establishment of the nation, without extensive reorganization of the established system.

When the old forebrain was superseded in evolution by the new brain (the new "TV set"), the old system was not discarded. Rather, the new system (neocortex) had been superimposed on the old one and in this fashion provided a fantastically complex analyzer-integrator service for information

[2] The Neurosciences Research Program sponsored by the Massachusetts Institute of Technology and supported by grants (GM-10211) from the National Institute of General Medical Sciences, National Institutes of Health, and (NsG-462) from the National Aeronautics Space Administration, is a joint study by some twenty-seven investigators in fields relevant to the neurosciences in their most fundamental aspects. The Program operates a center located in the House of the American Academy of Arts and Sciences in Brookline, Massachusetts, where a resident staff carry out the ongoing program of discussion and meetings.

filtering from the sensorium and passing through or bypassing the old brain's long-established analyzer-integrator system. This new system made possible most of the higher integrative functions, including language and the ability consciously to retrieve, process, and interpret information stored very recently or long ago. This differentiation required vast proliferation of the cells comprising the cerebral cortex; for each neuron in the old brain, two neurons were laid down in the neocortex. If the analogy of the brain's analyzer-integrator cortex, with the revision in organization needed to deal effectively with tomorrow's science, be even remotely apropos, it would suggest a vast proliferation of science personnel to analyze and integrate the information brought in from the laboratories and computer centers. What this could mean is highlighted by the fact that there are more individuals engaged in science today than in all past time. Perhaps Dr. Goudsmit's point provides a reassuring answer: in that day everyone will be a scientist.

Targets for Research in the Life Sciences

In the context of epochal discoveries in the natural sciences, the promise of revolutionary discoveries in the life sciences becomes ever more evident. Astrophysics has not only revealed the immensity of the universe and the finitude of man and his home planet but has suggested that man may not be alone in the universe. Methods may be available to test the possibility that sentient beings perhaps far surpassing man in their scientific and technological capabilities may populate many planets in this and other galaxies.

In demonstrating that matter and energy are interconvertible, that nature manifests a certain graininess—the quantum of action, which forever stands between man and "direct" contact with nature—that for each type of particle there is probably an antiparticle, man has penetrated to and discovered phenomena unimaginable from his experience with the macroworld. Perhaps the epithet "strange particle," applied to certain intranuclear particles, characterizes all such discoveries. Dr. Goudsmit looks to them to liberate man from the enslavement that results from faulty primitive conceptions of the universe. In a similar vein, what can be said of the promise in the life sciences?

The postwar development of molecular biology culminated in the breakthrough of molecular genetics, the success story of our day. Though in making a man the macromolecular code, which resides in the sperm and the egg, may now stand revealed in its spiral splendor, the mechanisms that direct its readout to bring about successive and appropriate stages of development remain obscure. The components are being identified, but the vital systems-type of regulatory phenomenon probably needs new conceptual and experimental tools.

Understanding of the human mind, by all odds, represents the greatest problem and carries the greatest promise in the life sciences and, as indicated by Schrödinger, probably in the whole of science. What is the status of this quest? Presently, the sciences related to the brain and to behavior stand far apart both in conceptual (component- versus systems-oriented) approach and in professional organization for research. Much would be gained by any activity that would help bridge the gap.

Innate, instinctual memory is clearly carried in code over chromosomal DNA, and it seems improbable that acquired memory is mediated by a completely different mechanism. Facts of psychology, neurophysiology, and neuro-anatomy support the view that long-term memory may not be explained at the level of neurons and their circuits; facts of molecular neurology suggest that the ability to process and retrieve such memory in cognitive behavior is carried in a macromolecular code of a type for which the neuron appears to be specially differentiated. Hence, the highly successful methodology and concepts of coding which have proved so valuable in molecular genetics stand ready for application in a science now emerging as an entity; molecular neurology.

As with the problem of goal-directed readout of the genetic code in development, the systems phenomena in their most basic aspect remain unknown, strangely refractory, and unyielding to powerful and concerted attack. Can it be that underlying such phenomena there may be something which, like the quantum of action and "strange particles," forms no part of human experience to date? But as those physical phenomena yielded to the attack of theoretical and experimental physics, so we may hope will those of the brain and mind. Perhaps in contrast to the strange particles of atomic physics we may discover "strange *systems*" underlying mental processes. Sensing mechanisms far more esoteric than the common ones of vision, audition, olfaction, etc., which developed outside the central nervous system, may exist inside the central nervous system. Some of these have already been discovered in the brain stem, where they preside over numerous vital processes such as the regulation of breathing, osmotic pressure, and temperature.

One may ask whether in the billions of cells and circuits in the brain, particularly in the vast uncharted areas of the old and the new "black boxes," there has emerged in man a mechanism capable of sensing thought itself. It would be as difficult to fashion experiments to test such a possibility as it was to investigate and understand the bizarre manifestation of lightning (balls of fire and other such phenomena which could not be reproduced in the laboratory) before the emergence of plasma theory. When the modalities employed in mental action are better understood, they may point the way to new physical principles. However, in the meantime the powerful methods of molecular- and systems-science should be marshaled in the study of the neuron-brain, brain-mind problem, for here may lie man's shining hope for the future, for liberation from the enslavement resulting from our preoccupation with the material—the atomic and molecular—aspects of nature which inhibit and retard the discovery of new hierarchies of sentience and knowledge, the leap from personal knowledge (*vide* Polanyi) to corporate, communal knowledge, from ruggedly individualistic science to corporate science. Will this challenge the imagination of scientists, citizens, and governments sufficiently to make a concerted effort to bring it about? Hopefully, the answer will be resoundingly in the affirmative.

ADDENDUM

C. M. Cade (in "Are we alone in space?" *Discovery,* Vol. 24, No. 4 (1963), pp. 27–34) writes: "The oldest stars in the galaxy are about 15 Aeons old—more than three times the age of the Earth—and there are stars of spectral types F, G, and K with ages of 9 to 10 Aeons, which could have planets on which life would have by now attained an age of at least 4 Aeons. We do not know how long it takes for intelligent life forms to develop, but judging from the only example which we know, it is roughly 2.5 Aeons. From this it follows that there may be inhabited planets in the Galaxy with civiliza-

tions older than 1.5 Aeons. . . . And judging from the ever-accelerating rate at which intelligence has developed in the higher forms of life on Earth, the older races of the cosmos must have attained intellectual heights which are completely beyond our comprehension."